Zoosymposia 9: 036–043 (2014)
www.mapress.com/zoosymposia/

ISSN 1178-9905 (print edition)
ZOOSYMPOSIA
ISSN 1178-9913 (online edition)

http://dx.doi.org/10.11646/zoosymposia.9.1.8
http://zoobank.org/urn:lsid:zoobank.org:pub:17AB1864-B6CC-4A1C-8F12-137044CD6540

Bathymetric distribution of aquatic Oligochaeta in Lake Kizaki, Central Japan

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Abstract

Bathymetric distribution of aquatic oligochaetes was studied at 8 stations with different depths (mean depth 16.7 ± 9.4 m, min. 5.3 m, max. 29.4 m) in July 2012 in mesotrophic Lake Kizaki, Nagano Prefecture, Central Japan. The average density was 10424 ± 5346 individuals m^{-2}. Oligochaetes were numerically dominant at all sampling stations. High density, sometimes more than 10000 individuals m^{-2}, was recorded at 3 stations (St. 4, 5, and 6) deeper than 18 m. Maximum density was 20561 ± 13864 individuals m^{-2} at Station 4 (depth 29.4 m, ignition loss of sediment 13.5%, bottom water temperature 8.1 °C and DO of bottom water 0.12 mg l^{-1}). We identified a total of 5 genera and 7 species belonging to three subfamilies: i.e., 1 species of Naidinae, 2 species of Rhyacodrilinae and 4 species of Tubificinae. Dominant species (in order of abundance) were *Tubifex tubifex* (Müller, 1774) (8550 ± 6317 individuals m^{-2}; 82.0%) and *Limnodrilus* spp. (*L. hoffmeisteri* Claparède, 1862 and *L. claparedeianus* Ratzel, 1868) (1710 ± 1383 individuals m^{-2}; 16.4%). *Tubifex* and *Limnodrilus* were obtained from every station, and the density of *T. tubifex* tended to be higher as the depth became greater, while *Limnodrilus* spp. was also widely distributed, but with a peak value at a depth of 5.3 m in the shallowest station. From the submerged plant zone, *Ophidonais serpentina* (Müller, 1773) was collected. An earlier study by Hirabayashi & Hayashi (1994) showed that in 1985 the average density of aquatic oligochaetes was 435 ± 428 individuals m^{-2}, oligochaetes dominated in only four locations and were distributed over the whole lake approximately equally. Comparisons of our data with the earlier studies have shown that oligochaete density has increased greatly according to Hirabayashi & Hayashi (1994). We suggest that a decrease in dissolved oxygen concentration of bottom water was due to an increase in organic matter content of the sediment. As a result, *T. tubifex* could expand their habitats in the profundal zone.

Key words: aquatic Oligochaeta, density, bathymetric distribution, Lake Kizaki, *Tubifex tubifex* (Müller, 1774)

Introduction

It has been reported that aquatic Oligochaeta play an important role in the material flows in lake ecosystems, especially the detrital food chain (Brinkhurst & Jamieson 1971). In Japan, however, there have been few ecological studies on aquatic Oligochaeta in lakes up to the present, because of the difficulty of species identification.

In Lake Kizaki, Miyadi (1931) conducted a descriptive study of aquatic Oligochaeta. Kitagawa (1973) and Hirabayashi & Hayashi (1994) reported on the horizontal distribution of total aquatic Oligochaeta. However, their studies left something to be desired from the ecological point of view. Recently, Hirabayashi *et al.* (2007) reported the seasonal changes in depth distribution of aquatic oligochaeta in the southern part of Lake Kizaki. They indicated that the dominant species were *Tubifex tubifex* (Müller, 1774) (9737 individuals m^{-2}; 81.0%) and *Limnodrilus* spp. (1876 individuals m^{-2}; 15.6%). *T. tubifex* was obtained from all three investigation stations, and its density tended to be higher as the depth was greater. However, Hirabayashi *et al.* (2007) only collected the samples at three different depth sampling stations in the southern part of Lake Kizaki. Thus, the purpose of this study is to clarify the characteristics of oligochaetes and their depth distribution throughout Lake Kizaki.

 Accepted by Adrian Pinder: 2 Dec. 2013; published: 12 Jun. 2014

Materials and methods

Study site

Lake Kizaki is located at the eastern foot of Japan's Northern Alps (764 m above sea level) along the tectonic zone or Fossa Magna which traverses the main island (Honshu) of Japan (36' 33'N. 137' 50'E). It has an area of 1.4 km^2, a maximum depth of 29.5 m, and a mean depth of 17.9 m. There are two main inflowing rivers, the Nakanogu and Inaozawa, while the Shimonogu is the only river flowing out of the lake's southern end (Fig. 1). The lake's eastern shore is partly surrounded by cultivated land. Villages occupy its northwestern and southern shores. The lake is covered by ice from late January to mid-March with a relatively stable summer thermocline.

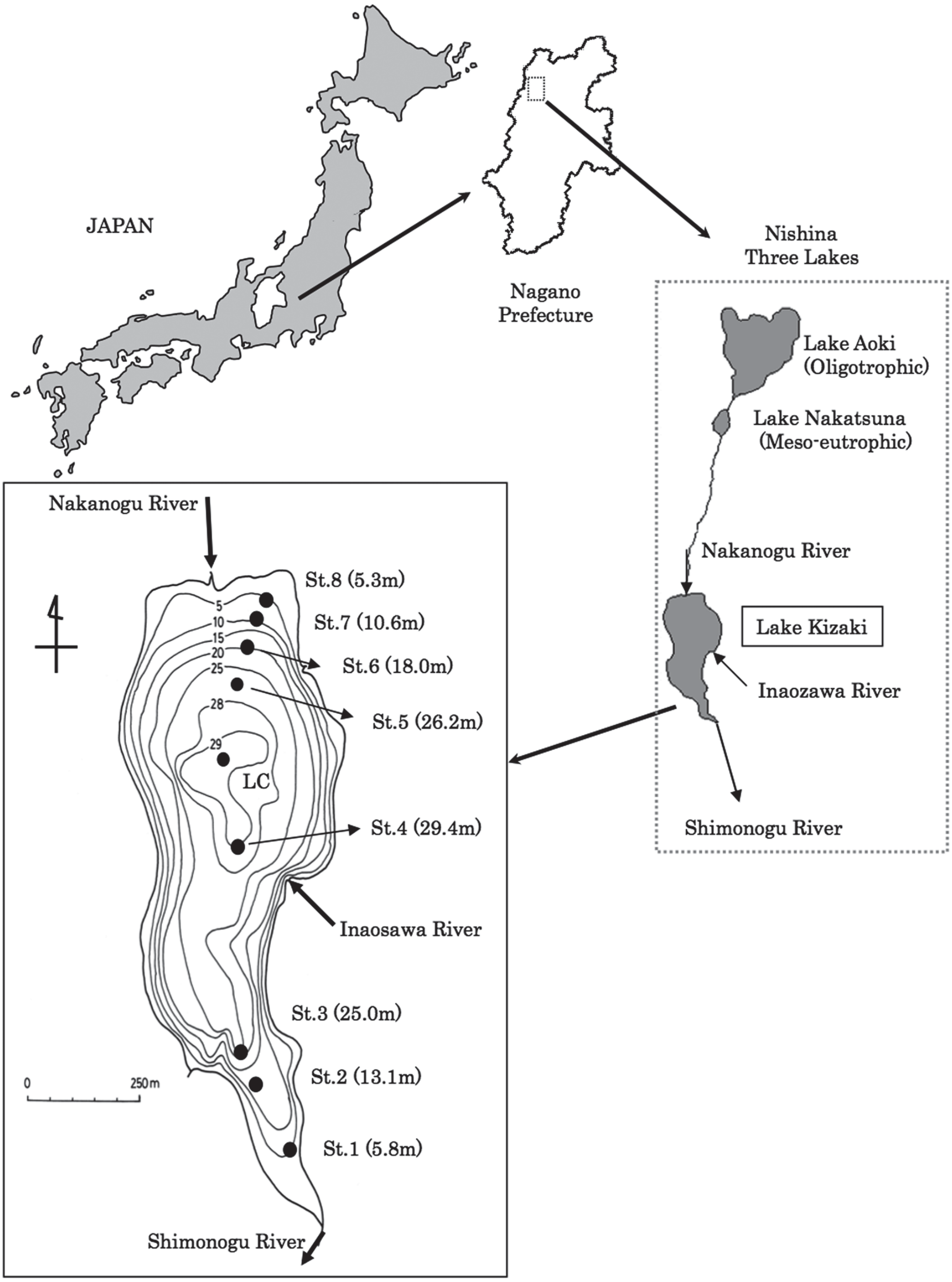

FIGURE 1. Maps showing location of Lake Kizaki, isopleths of depth (m), and sampling stations in the lake.

Many limnological studies have been done since the first major work by Tanaka (1930). Transparency averaged about 5 m until 1950 (Saijo 1983), but had decreased to approximately 3 m by 1970 (Hayashi 1989). From the end of the 1970's to the 1980's the biota and the environment of the lake changed drastically (Hayashi 1990). Since the end of the 1970's, *Anabaena* has bloomed annually in July-August (Watanabe *et al.* 1985), and the changes in water coloration have increased in frequency due to an abundance of microorganisms which graze upon *Anabaena* (Funakoshi *et al.* 1985). In the autumn of 1987, the dinoflagellate *Peridinium bipes* grew explosively, forming a freshwater red tide (Park & Hayashi 1993). Aizaki *et al.* (1981) ranked this lake as mesotrophic, using the modified Carlson's trophic state index based on chlorophyll-a, total phosphorus, and transparency. Such an alteration of the lake environment must have caused some changes in the bottom fauna, especially dominant Chironomidae and Oligochaeta (Hirabayashi & Hayashi 1994; Hirabayashi *et al.* 2007).

Collection of Oligochaeta

A survey of Oligochaeta was carried out on 13 July 2012, using a standard Ekman-Birge grab (15 x 15 cm). Three replicate sediment samples were taken at each of 8 sampling sites in Lake Kizaki (5.3–29.4 m depth; Fig. 1). The sampling points were determined with a Global Positioning System (GPS). After sieving the sediment through a Surber net (NGG 66: 250 µm mesh size), Oligochaeta were arranged against a white and / or black background using a binocular microscope (magnification 10 x and 20 x) and put into a glass bottle with 10% formaldehyde solution. They were used for species identification, and the individual numbers of each species were counted and their wet weight measured. For species identification, Amman’s lactophenol preparation method (Brinkhurst 1971) was adopted. They were identified using the keys of Brinkhurst (1971), and Kathman & Brinkhurst (1999). In addition, chironomid and chaoborid larva were picked up and counted in the laboratory.

Physical environmental factors

Bottom sediment samples for organic matter content analysis were collected with a core sampler (three cm inner diameter) at each sampling site. The mud in the upper three-cm layer of each core was oven-dried at 110 °C for 2 days and ignited in a muffle furnace at 550 °C for three hours to determine the ignition loss (IL). The core sampler was also used to measure dissolved oxygen concentrations (DO) and water temperature in the water at the mud-water interface. The water near the mud surface in the core sampler (which remained above the sediment in the core sampler when it was pulled from the water) was siphoned carefully into a glass bottle. The dissolved oxygen concentration was measured with the Winkler method with azide modification. The water temperature (WT) also was measured, using a thermistor thermometer. Correlations between environmental variables such as depth, IL, WT and DO and oligochaetes densities were examined with the Kendal rank correlation test, utilizing a computer program package (NAP Ver. 4, Igaku-Shoin, Tokyo, Japan).

Results

Physical environmental factors

Table 1 shows the physical environmental factors in the bathymetric sampling survey in Lake Kizaki, 13 July 2012. The bottom water temperature ranged from 6.8 (St. 3) to 22.3 °C (St. 8). In sites shallower than 6 m, i.e., at St. 1 and 8, the bottom water temperature was over 20 °C. On the other hand, in sites deeper than 20 m, it ranged below 8 °C. The dissolved oxygen concentrations in bottom water ranged from 0.1 (St. 4) to 7.7 mg l^{-1} (St. 7). In sites shallower than 6 m, the dissolved oxygen concentrations were over 7.0 mg l^{-1} and in sites deeper than 25 m they were below 3 mg l^{-1}. The values of loss on ignition of the upper 3 cm of the sediment taken from 8 locations ranged from 1.2% (St. 1, sand) to 14.8% (St. 5, mud). Most of the lake basin consisted of soft bottom with organic matter contents higher than 10%. Sediments at St. 5 contained the highest levels of organic matter (14.8%) of all the stations.

TABLE 1. Physical environmental factors in the bathymetric sampling survey in Lake Kizaki, 13 July 2012.

Station No.	Depth (m)	Bottom water Temp. (°C)	D.O. (mg/L)	Ignition loss (%)	Remarks
1	5.8	20.3	7.7	1.2	Sandy mud, *Elodia nuttari*
2	13.1	9.9	6.9	11.3	Mud
3	25	6.8	2.5	14.5	Mud
4	29.4	7.9	0.1	13.5	Mud
5	26.2	7.6	0.8	14.8	Mud
6	18	9.7	5.4	14.5	Mud
7	10.6	12.1	6.9	10.1	Mud
8	5.3	22.3	7.4	1.8	Sandy mud, *Elodia nuttar*i

Mean values and standard deviations of the densities of Oligochaeta

In our study, based on environmental factor observation (Table 1) and recent oligochaete observations (Hirabayashi *et al.* 2007), we divided the lake into two zones: a littoral zone covered with submerged plants, *Elodia nuttallii*, (6 m <) and another area (> 6 m). A list of the benthic macroinvertebrates (chironomid and chaoborid larvae and oligochaetes) collected at 8 stations in Lake Kizaki on 13 July 2012 is presented in Table 2. The average densities of chironomid and chaoborid larvae and oligochaetes for all the stations were 2261±1823 (17.8%), 20±25 (0.2%) and 10424 ± 5346 (82.0%) individuals m^{-2}, respectively. Chironomid larvae and oligochaetes were collected at all 8 stations, but chaoborid larvae were not collected at Stations 2, 6 and 8. The highest Oligochaeta densities were measured at St. 4 (20561 ± 13864 individuals m^{-2}) and the fewest were collected at St. 1 (3422 ± 2252 individuals m^{-2}) with an approximate ratio of 6 : 1. We identified a total of 5 genera and 7 species belonging to three subfamilies, i.e., 1 species of Naidinae, 2 species of Rhyacodrilinae and 4 species of Tubificinae. The most abundant genus was *Limnodrilus* (3 species). In this study, aquatic Oligochaeta in Lake Kizaki were dominated by two species (in order of abundance); *T. tubifex* (8550 ± 6317 individuals m^{-2}; 82.0%), *Limnodrilus hoffmeisteri* Claparède, 1862 and *Limnodrilus claparedeianus* Ratzel, 1868 (1710 ± 1383 individuals m^{-2}; 16.4%). In *L. hoffmeisteri* and *L. claparedeianus*, immature worms are difficult to distinguish; they are shown as *Limnodrilus* spp. in Table 3. These two groups accounted for 98.4% of the overall total individual numbers. Seven species were present at St. 1 and 8 (< 6 m), making these the stations with the highest number of species, against only 2 species from St. 2 to 7 (> 6 m). Less than 6 m depth, *Limnodrilus* spp. (3755 ± 1233 individuals m^{-2}; 84.1%) were dominant, while *T. tubifex* was dominant at more than 6 m (> 6 m) (11382 ± 4167 individuals m^{-2}; 91.7%). *T. tubifex* and *Limnodrilus* spp. were common to all of the stations. On the other hand, the other 4 species were only collected at St. 1 and 8.

The population density of each Tubificidae species differed among the sampling stations. As shown in Figure 2, the bathymetric distribution of mean densities (± SD) of the total oligochaetes, *T. tubifex* and *Limnodrilus* spp. in Lake Kizaki was measured on 13 July 2012. Oligochaetes were abundant at all stations with a peak value at 29.4 m at the deepest station (St. 4). *T. tubifex* was widely distributed, with a peak value at the deepest station. *Limnodrilus* spp. was also collected from all stations, but with a peak value at a depth of 5.3 m in the shallowest station.

Table 3 presents the correlation matrix of the densities of total oligochaetes, *T. tubifex*, and *Limnodrilus* spp., as well as the environmental factors. The densities of *T. tubifex* exhibited a positive correlation with water depth and ignition loss, and a negative correlation with bottom water temperature and dissolved oxygen concentration. The density of *Limnodrilus* spp. exhibited a positive correlation with bottom water temperature, and a negative correlation with ignition loss.

TABLE 2. Mean values and standard deviations (SD) of the densities and proportion of Oligochaeta, and chironomid and chaoborid larvae in Lake Kizaki, 13 July 2012.

Tubificidae	< 6 m (St. 1 and St. 8) Mean densities (Ind. m^{-2})	Proportion (%)	> 6 m (from St. 2 to St. 7) Mean densities (Ind. m^{-2})	Proportion (%)	Total (all stations) Mean densities (Ind. m^{-2})	Proportion (%)
Naidinae						
Ophidonais serpentina	360±118	(8.1)	0±0	(0.0)	90±172	(0.9)
Rhyacodrilinae						
Bothrioneurum vejdovskyanum	266±88	(6.0)	0±0	(0.0)	67±128	(0.6)
Branchiura sowerbyi	1.5±0.7	(0.03)	0±0	(0.0)	0.4±0.7	(0.004)
Tubificinae						
Tubifex tubifex	54±17.7	(1.2)	11382±4167	(91.7)	8550±6317	(82.0)
Limnodrilus hoffmeisteri + *Limnodrilus claparedeianus*	3755±1233	(84.1)	1028±377	(8.3)	1710±1383	(16.4)
Limnodrilus grandisetosus	27±8.5	(0.6)	0±0	(0.0)	6.8±13	(0.07)
Others	1.5±0.7	-0.03	0±0	0	0.4±0.7	-0.004
Total mean oligochaete density	4465±1467	(100.0)	12410±4543	(100.0)	10424±5346	(100.0)
Total mean chironomid density	2200±1267	-	2281±2033	-	2261±1823	-
Total mean chaoborid density	7±18	-	25±41	-	20±25	-

TABLE 3. Correlation matrix for environmental variables and densities of oligochaetes in Lake Kizaki on 13 July 2012, based on Kendal rank correlation test.

	Depth	DO	WT	IL	Total Oligochaeta	*Tubifex tubifex*	*Limnodrilus* spp.
Depth	-	-0.96**	-0.87**	0.81*	0.86**	0.88**	-0.56
DO		-	0.69	-0.65	-0.80*	-0.77*	0.32
WT			-	-0.98**	-0.72*	-0.85**	0.88**
IL				-	0.72	0.81*	-0.76*
Total Oligochaeta					-	0.97**	-0.43
Tubifex tubifex						-	-0.63

DO: dissolved oxygen concentration, WT: bottom water temperature, IL: ignition loss

Discussion

One Naidinae species, *Ophidonais serpentina* (Müller, 1773), was captured only at St. 1 and 8 (Table 2). This species is well known to inhabit an aquatic plant zone and live among macrophytes (Timm & Veldhuijzen van Zanten 2003). Ohtaka & Iwakuma (1993), and Ohtaka & Nishino (1995; 1999; 2006) reported this species was collected at a submerged plant area in Lake Yunoko and Lake Biwa, Japan. According to Nagasaka (2004), patchy *E. nuttallii* cover was observed around St. 1 and 8 in Lake Kizaki, and we collected *E. nuttallii* with the benthic samples. Higuchi *et al.* (2005) also reported high densities of *Vallisneria asiatica* Miki (< 2 m depth) and *Nitella flexilis* (Linnaeus) C. Agardh, 1824 were observed in the western and northern parts of Lake Kizaki, recently. *O. serpentina* might use these submerged plant body surfaces as a habitation place. Higuchi *et al.* (2005) also reported that the vertical growth limits of submerged plants was c.a. 9 m in Lake Kizaki and *E. nuttallii* mainly inhabited from 2 - 5 m and *N. flexilis* inhabited from 6 – 9 m (mixed in 5 – 6 m), so the distribution of *O. serpentina* would depend on the distribution pattern of submerged plants in Lake Kizaki. According to Hirabayashi *et al.* (2007), they described two Naidinae species, *Uncinais uncinata* and *Pristina aequiseta*, from the submerged plant zone, and *U. uncinata* was captured only in August and October, while *P. aequiseta* was captured during the winter (only in December and March). In our study, we did not collect these species. In regions shallower than St. 8 and 1, there were many kinds of submerged plants (Nagasaka 2004; Higuchi *et al.* 2005) which provided many types of habitats for Oligochaeta. Thus, it is necessary to investigate in more detail the distribution of aquatic Oligochaeta in shallower regions (<5 m) of this lake.

At St. 1 and 8 (shallower regions, < 6 m), *T. tubifex* comprised 1.2% of all oligochaetes against 91.7% from St. 2 to St. 7 (deeper regions, > 6 m) (Table 2). At the deeper regions (> 6 m) dissolved oxygen concentration decreased with increasing water depth. In particular, the oxygen concentration of bottom water fell below 1 mg l^{-1} at St. 4 and 5 (Table 1). At these stations, *T. tubifex* was the most abundant species (Figure 2). Berg *et al.* (1962) reported that *T. tubifex* tolerated low oxygen concentration conditions: i.e., it was able to regulate its rate of oxygen consumption down to a concentration of only 0.6 mg l^{-1}. Thus, it might be that this species could expand their habitats in the profundal zone in Lake Kizaki.

We compared our results with those of Hirabayashi & Hayashi (1994), and tried to clarify the relationship between the change of the organic matter contents (IL) of the sediments and the densities of the total oligochaetes in Lake Kizaki. Hirabayashi & Hayashi (1994) showed that in 1985 the average density of aquatic oligochaetes was 435 ± 428 individuals m^{-2}, oligochaetes dominated in only four locations and were distributed over the whole lake approximately equally (> 20 m depth stations; IL was 12.0 ± 1.5%). In our results, the average density of aquatic oligochaetes was 10424 ± 5346 individuals m^{-2}, oligochaetes dominated at all stations (> 20 m depth stations; IL was 14.3 ± 0.7%) and oligochaete densities increased greatly (ca. 24 times) compared with those of Hirabayashi & Hayashi (1994). Brinkhurst (1974) reported that the organic matter contents of sediments and the dissolved oxygen concentration near the bottom are the most important factors determining the abundance of oligochaetes in lakes. According to Newrkla & Wijegoonawardana (1987), oligochaetes are able to increase in number with increasing sediment organic matter content, mainly because such an increase results in an increased number of bacteria. These bacteria can play a role in transforming relatively refractory detritus into more nutritious form or can serve as a direct food for oligochaetes (Baker & Bradnam, 1976), that is, the dissolved oxygen was consumed by bacterial activity near the bottom. More recently, Hirabayashi *et al.* (2007) reported the dissolved oxygen concentration near the bottom decreased to 0.1 mg l^{-1} from August to December at the center of lake (< 25 m depth). This may be why the oligochaete density, especially *T. tubifex*, in the lake, was about 24 times the level previously observed in 1985. We suggest that the decrease in dissolved oxygen concentration of bottom water was due to an increase in organic matter content of the sediment. As a result, *T. tubifex* could expand their habitats in the profundal zone.

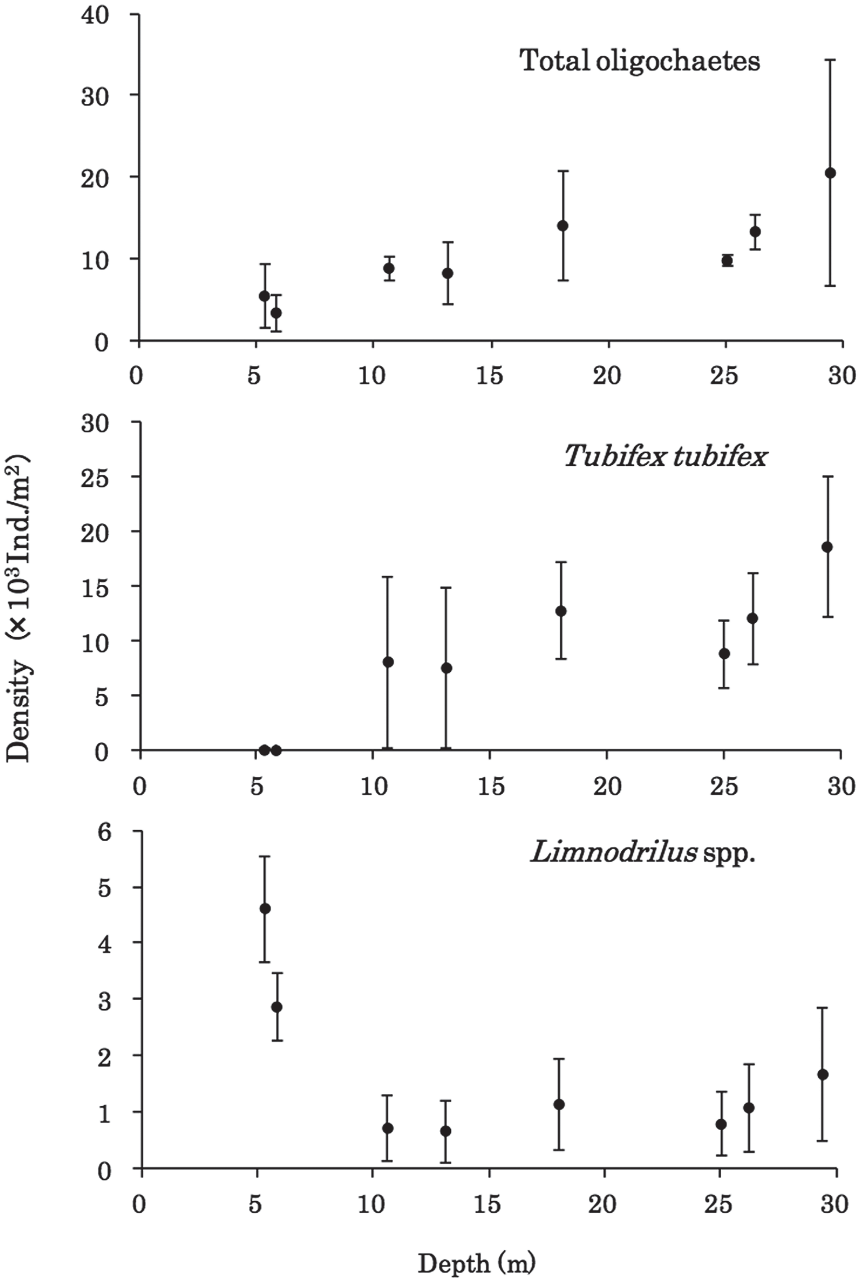

FIGURE 2. Bathymetric distribution of mean densities (± SD) of the total oligochaetes, *T. tubifex* and *Limnodrilus* spp. in Lake Kizaki, 13 July 2012.

Acknowledgements

We wish to express our thanks to Dr. A. Ohtaka of the Department of Natural Science, Faculty of Education, Hirosaki University, for his considerable assistance, taxonomical advice and valuable suggestions.

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